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(54) **SAFETY COMPLIANT CATALYST HEATING
AFTERTREATMENT SYSTEM**

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(57) **ABSTRACT**

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F01N 3/20 (2006.01)
(52) **U.S. Cl.**
CPC **F01N 3/2013** (2013.01)

A power converter apparatus includes a parent circuit board comprising a first surface, a second surface, and a thermal conductor core disposed intermediate the first surface and the second surface. A first child circuit is board mounted on the parent circuit board. A first plurality of power switches are mounted on the first child circuit board. A second child circuit is board mounted on the parent circuit board. A second plurality of power switches are mounted on the second child circuit board. A first heat transfer circuit includes a first set of conductors thermally conductively coupling the first plurality of power switches with the thermal conductor core. A second heat transfer circuit includes a second set of conductors thermally conductively coupling the second plurality of power switches with the thermal conductor core.

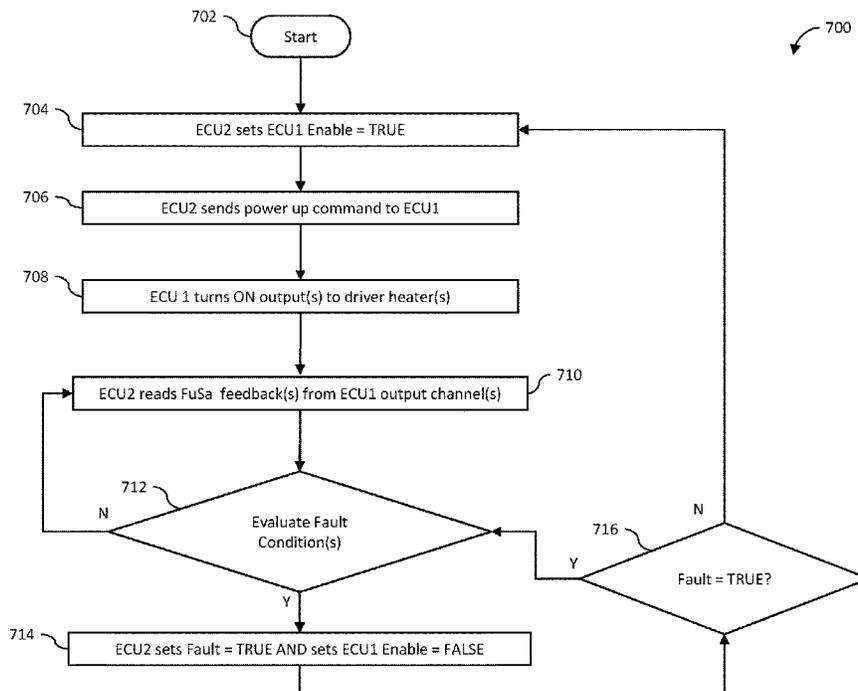
(58) **Field of Classification Search**
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3/2013; F01N 5/02; F01N 11/002; F01N
2240/16; F01N 2900/04
See application file for complete search history.

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22 Claims, 7 Drawing Sheets



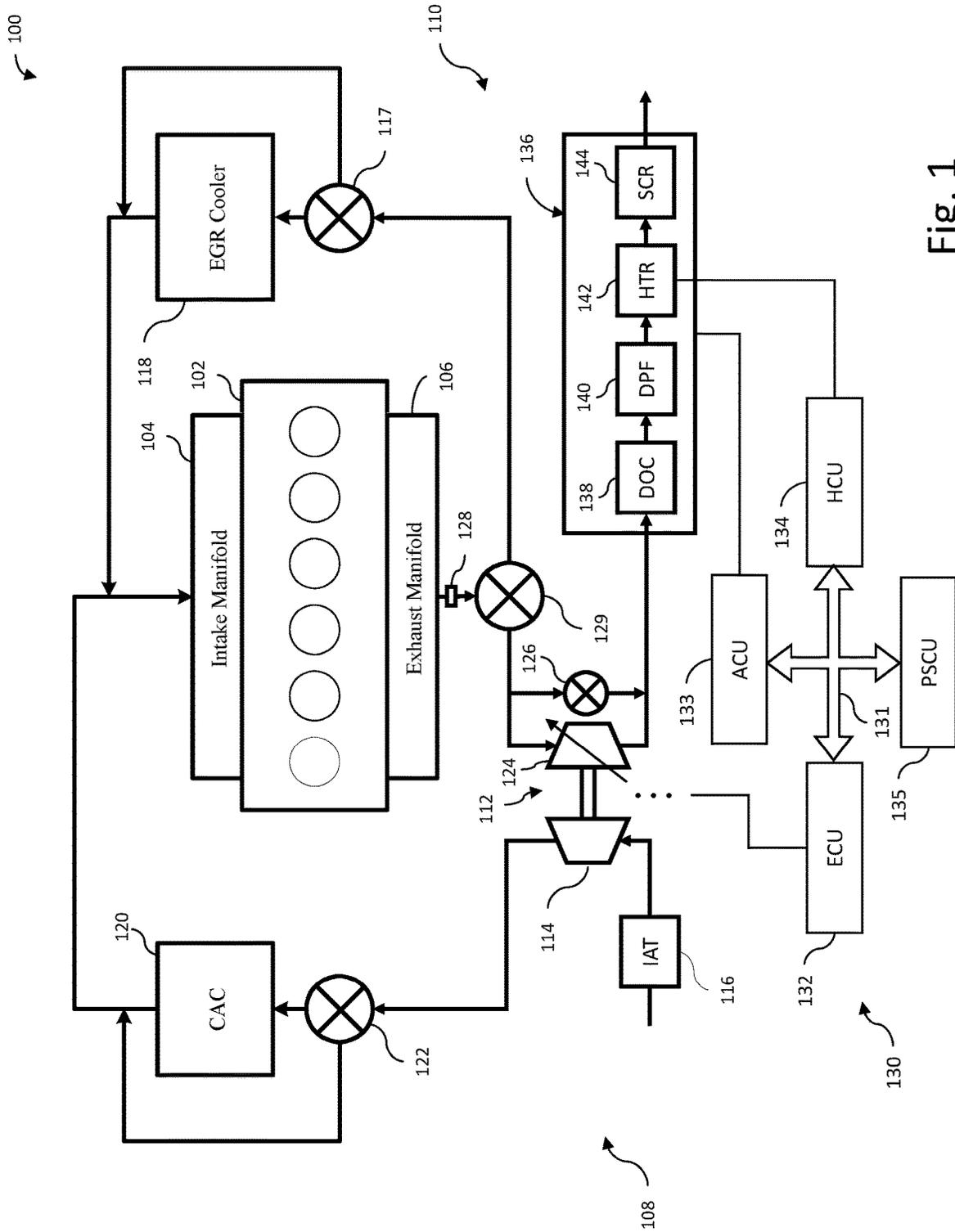


Fig. 1

230 ↖

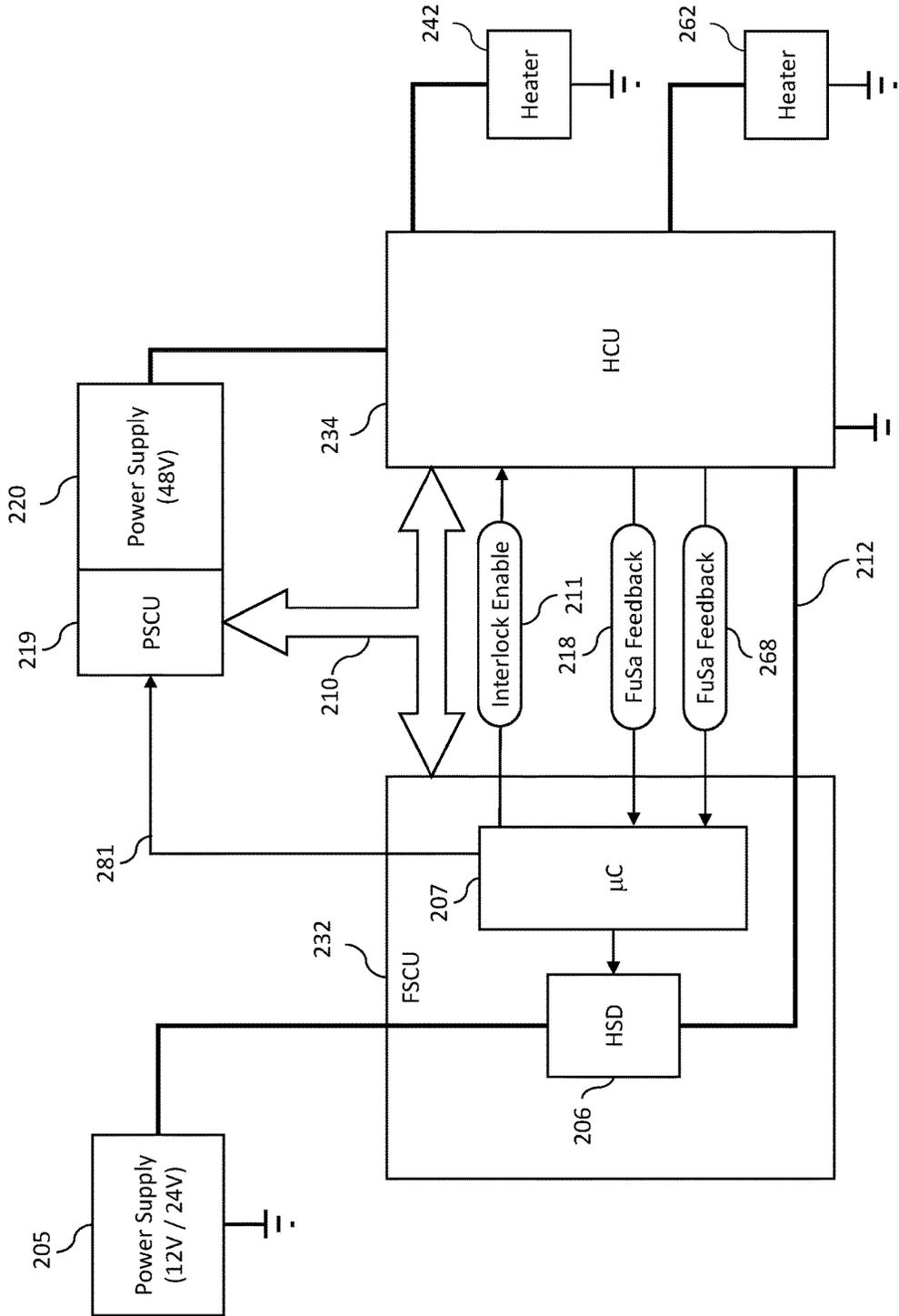


Fig. 2

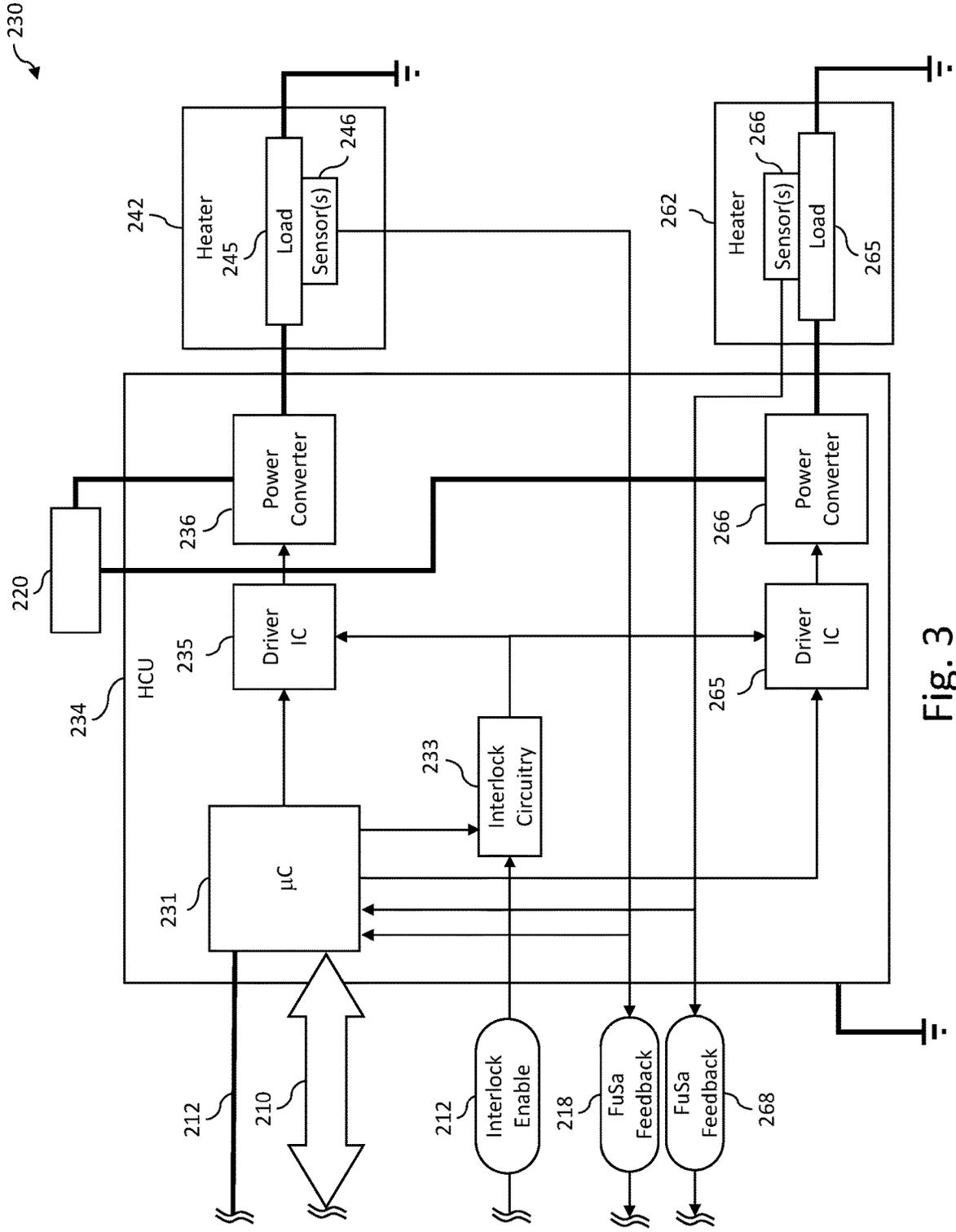


Fig. 3

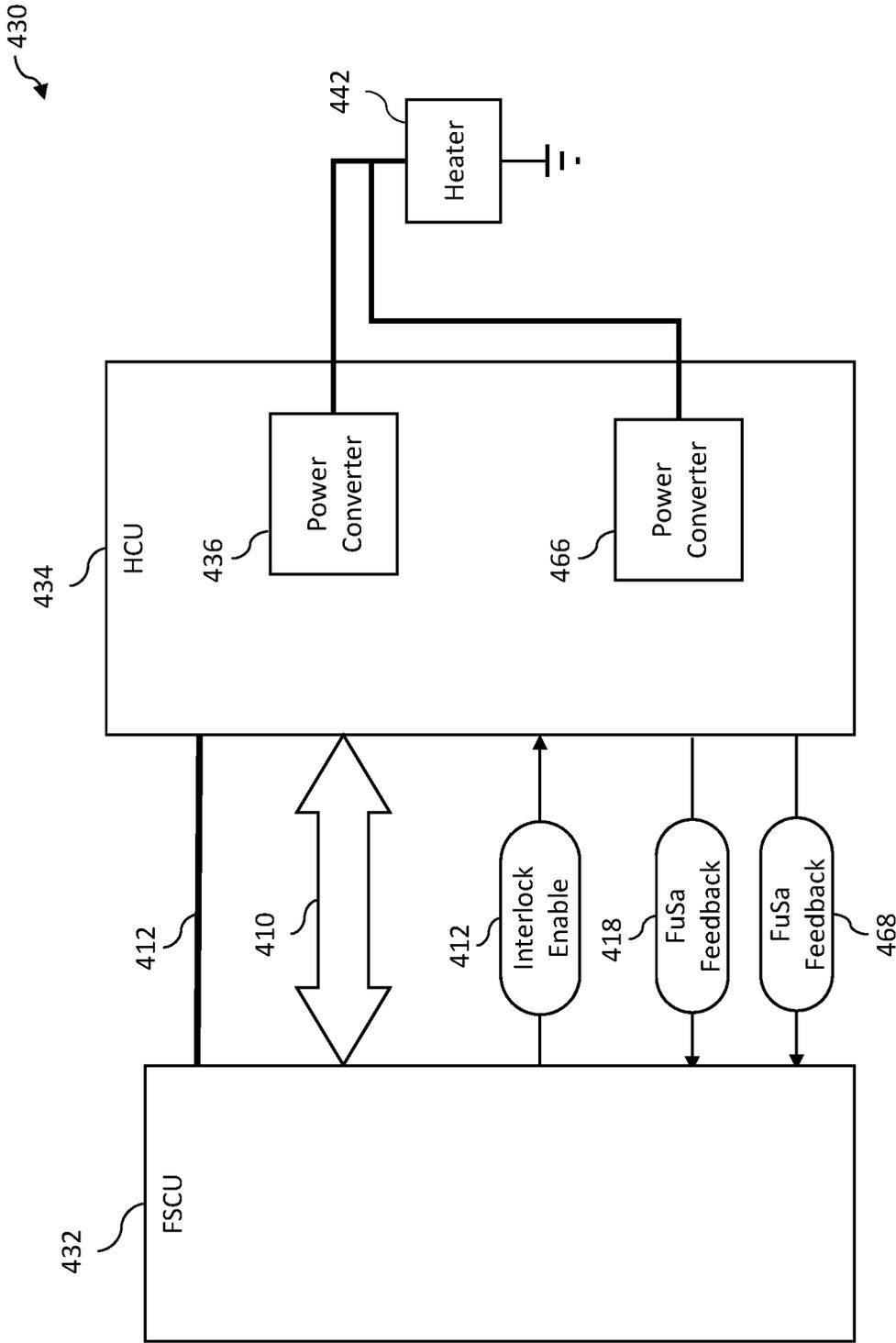


Fig. 4

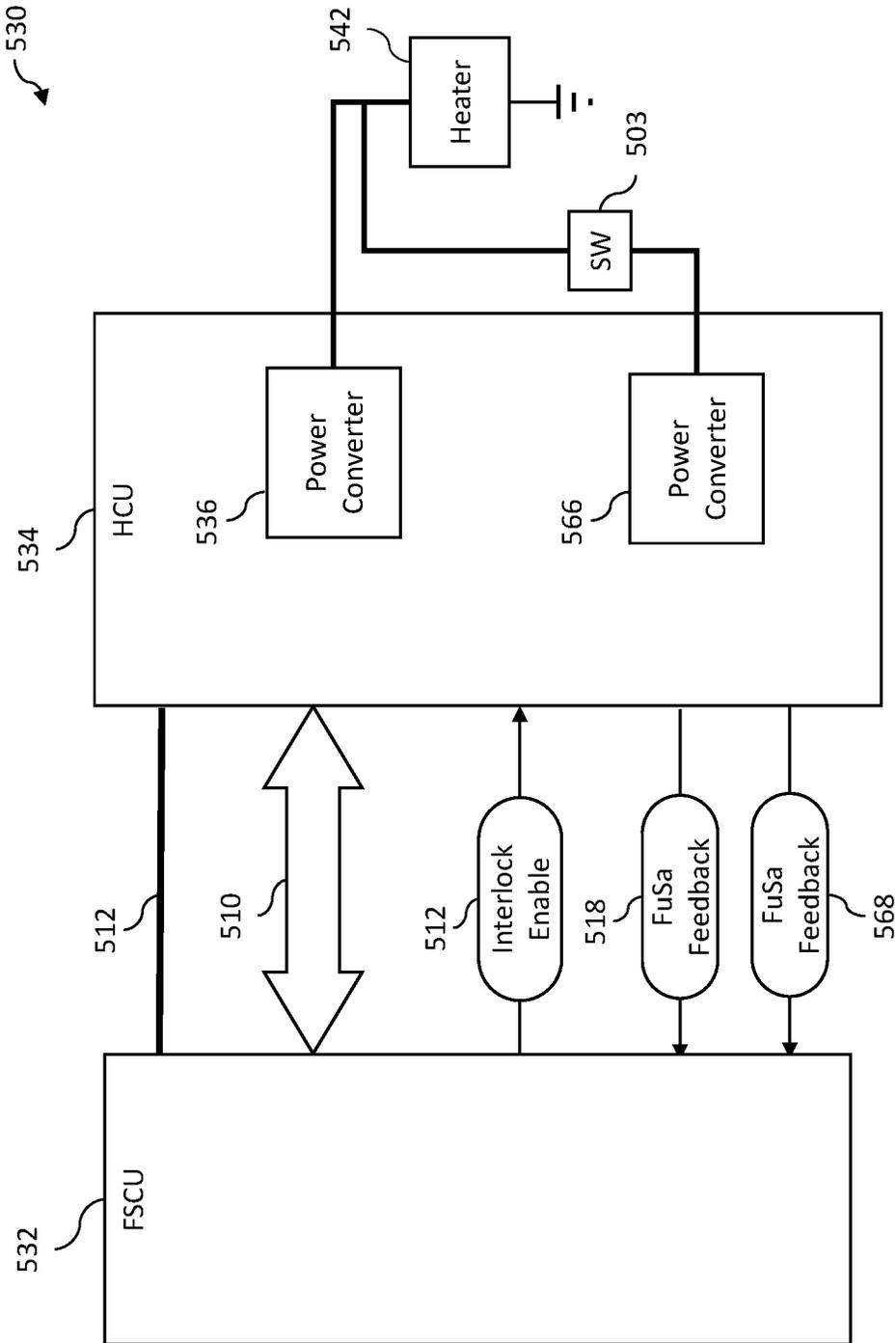


Fig. 5

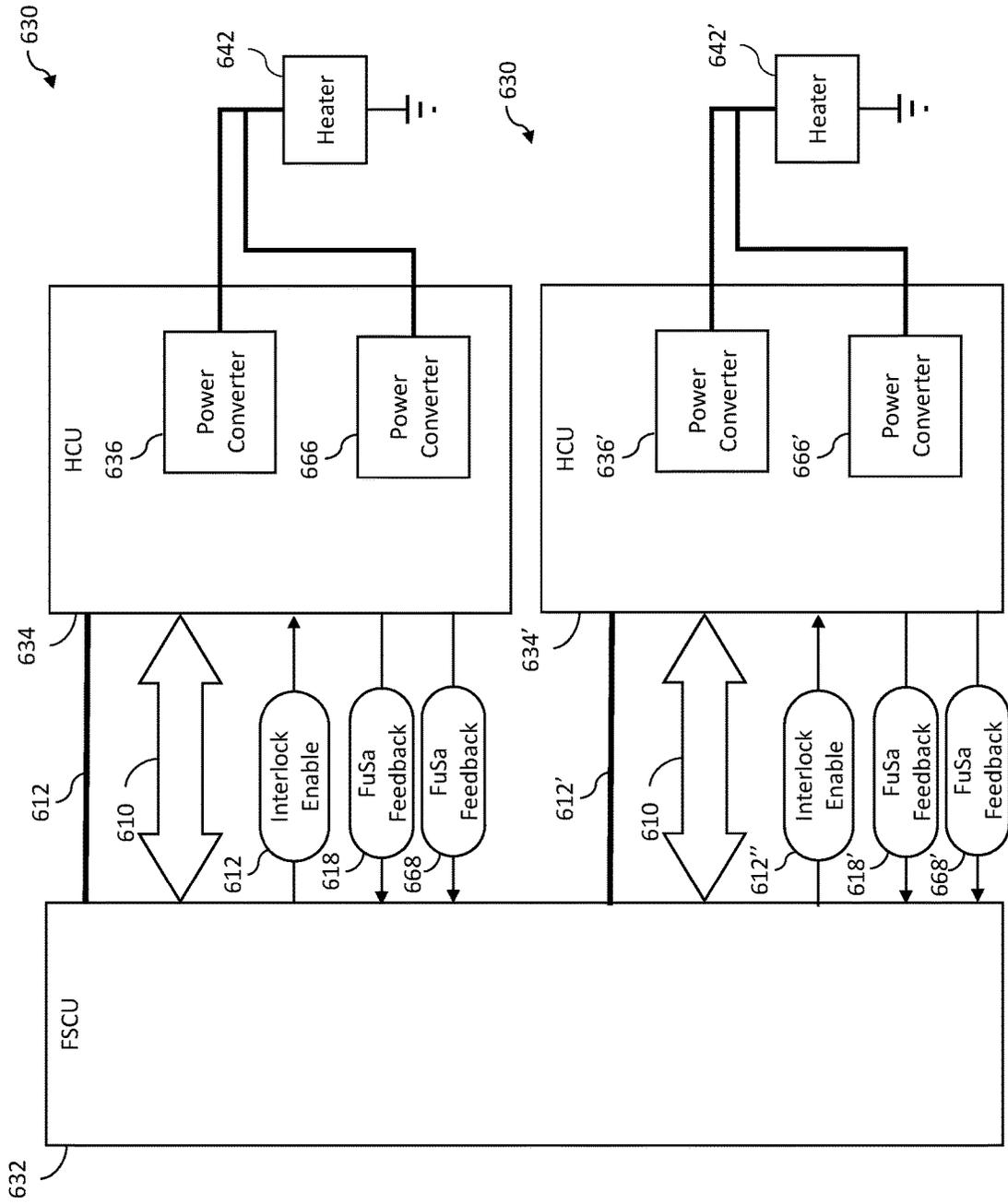


Fig. 6

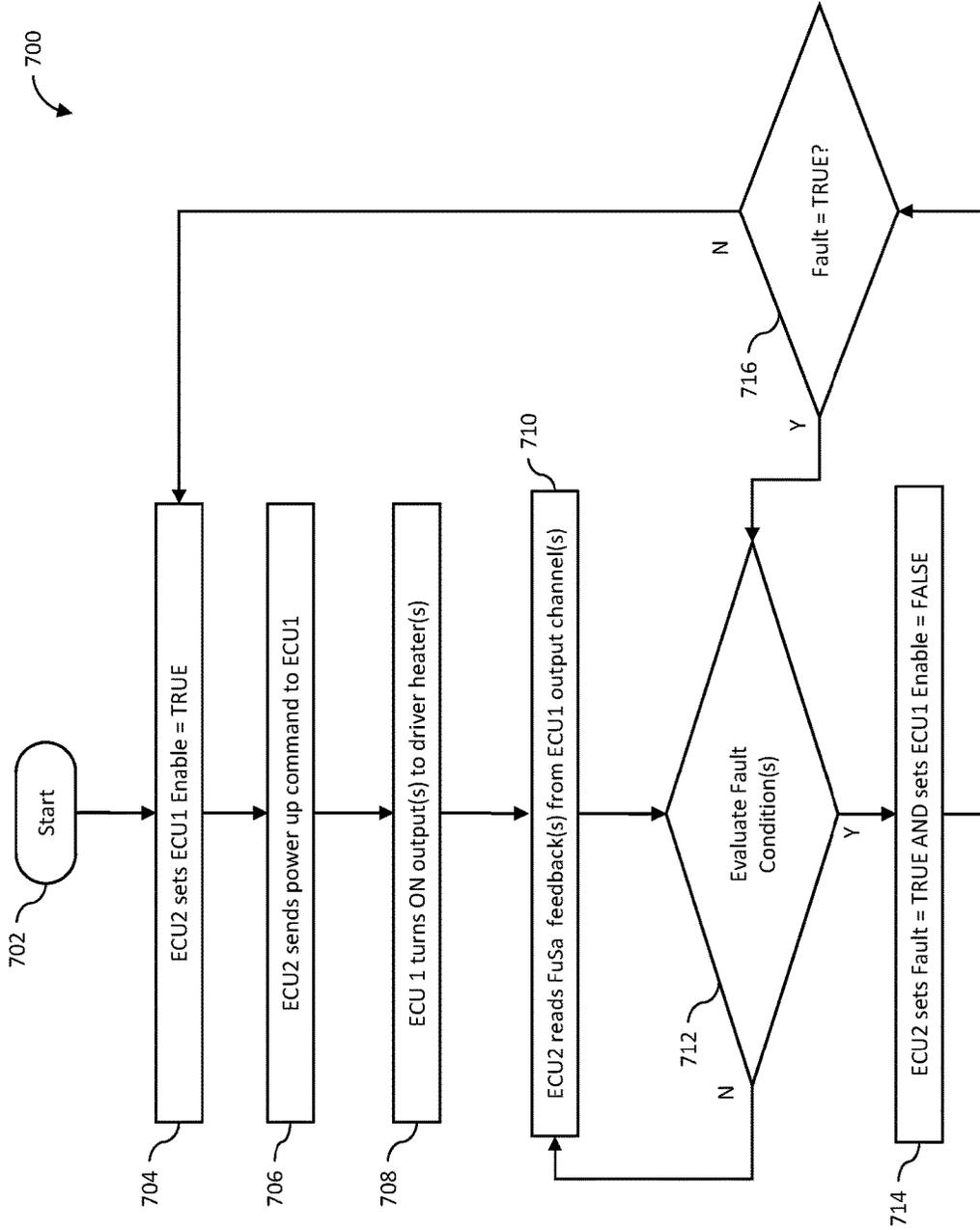


Fig. 7

SAFETY COMPLIANT CATALYST HEATING AFTERTREATMENT SYSTEM

BACKGROUND

The present application relates to safety compliant catalyst heating aftertreatment systems and related apparatuses, processes, systems and techniques. A number of proposals have been made for heating catalysts of aftertreatment systems for internal combustion systems. Existing approaches to aftertreatment catalyst heating suffer from a number of disadvantages, drawbacks, problems, and shortcomings including those respecting complexity, cost, reliability, and safety, among others. There remains a significant need for the unique apparatuses, processes, and systems disclosed herein.

DISCLOSURE OF EXAMPLE EMBODIMENTS

For the purposes of clearly, concisely, and exactly describing example embodiments of the present disclosure, the manner, and process of making and using the same, and to enable the practice, making and use of the same, reference will now be made to certain example embodiments, including those illustrated in the figures, and specific language will be used to describe the same. It shall nevertheless be understood that no limitation of the scope of the invention is thereby created, and that the invention as set forth in the claims following this disclosure includes and protects such alterations, modifications, and further applications of the example embodiments as would occur to one skilled in the art with the benefit of the present disclosure.

SUMMARY OF THE DISCLOSURE

Some embodiments include unique safety compliant catalyst heating aftertreatment apparatus. Some embodiments include unique safety compliant catalyst heating aftertreatment systems. Some embodiments include unique safety compliant catalyst heating aftertreatment processes. Further embodiments, forms, objects, features, advantages, aspects, and benefits shall become apparent from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram illustrating certain aspects of an example prime mover system.

FIGS. 2, 3, 4, 5, and 6, are schematic diagrams illustrating certain aspects of example electronic control system implementations.

FIG. 7 is a flowchart illustrating certain aspects of an example control process.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

With reference to FIG. 1, there is illustrated an example prime mover system **100** (also referred to herein as system **100**) including a prime mover in the form of an internal combustion engine (ICE) **102**. System **100** may be provide in a number of forms including, for example, in the form of a vehicle or vehicle powertrain system (e.g., an on-highway vehicle or vehicle powertrain system or an off-highway vehicle or vehicle powertrain system), a work machine or work machine powertrain system, a genset or genset powertrain system, or a hydraulic fracturing rig or hydraulic

fracturing rig powertrain system, to name several non-limiting examples. In shall be appreciated that system **100** may include a number of other components as will occur to one of skill in the art with the benefit and insight of the present disclosure. Furthermore, while engine **102** is provided as a prime mover of system **100** in the illustrated embodiment, other embodiments may comprise other types of prime movers, for example, battery electric drive systems, hybrid ICE-battery electric systems, a fuel cell electric drive system, or prime mover systems comprising combinations of the foregoing and/or other types of prime mover system as will occur to one of skill in the art with the benefit and insight of the present disclosure.

System **100** includes an intake system **108** and an exhaust system **110**. The engine **102** is in fluid communication with the intake system **108** through which charge air enters an intake manifold **104** and is also in fluid communication with the exhaust system **110**, through which exhaust gas resulting from combustion exits by way of an exhaust manifold **106**. The engine **102** includes a number of cylinders (e.g., cylinders **1** through **6**) forming combustion chambers in which a charge flow mixture of fuel and air is combusted. For example, the energy released by combustion powers the engine **102** via pistons in the cylinders connected to a crankshaft. Intake valves control the admission of charge air into the cylinders, and exhaust valves control the outflow of exhaust gas through exhaust manifold **106** and ultimately to the atmosphere. It shall be appreciated that the exhaust manifold **106** may be a single manifold or multiple exhaust manifolds.

The turbocharger **112** includes a compressor **114** configured to receive filtered intake air via an intake air throttle (IAT) **116** of the intake system **108** and operable to compress ambient air before the ambient air enters the intake manifold **104** of the engine **102** at increased pressure. The air from the compressor **114** is pumped through the intake system **108**, to the intake manifold **104**, and into the cylinders of the engine **102**, typically producing torque on the crankshaft. IAT **116** is flow coupled with a charge air cooler (CAC) **120** which is operable to cool the charge flow provided to the intake manifold **104**. The intake system **108** also includes a CAC bypass valve **122** which can be opened to route a portion or all of the charge flow to bypass the CAC **120**. Adjusting the bypass position of the CAC bypass valve **122** increasingly raises the temperature of the gas returned to the intake manifold **104**.

It is contemplated that in system **100**, the turbocharger **112** may be a variable geometry turbocharger (VGT) or a fixed geometry turbocharger. A variable geometry turbine allows significant flexibility over the pressure ratio across the turbine. In diesel engines, for example, this flexibility can be used for improving low speed torque characteristics, reducing turbocharger lag and driving exhaust gas recirculation flow. In an example embodiment, the VGT **124** can be adjusted to increase engine load and thereby configured to increase exhaust gas temperature. System **100** also includes a turbine bypass valve **126** to bypass the turbocharger **112**. Since cooler ambient air is introduced at the turbocharger **112**, opening the turbine bypass valve **126** allows for the turbocharger **112** to be bypassed and maintain a higher intake air temperature at the intake manifold **104**.

The exhaust system **110** includes an exhaust gas temperature sensor **128** to sense the temperature of the gas exiting the exhaust manifold **106**. The exhaust system **110** includes an exhaust gas recirculation (EGR) valve **129** which recirculates a portion of exhaust gas from the exhaust manifold **106** back to the intake manifold **104**. The exhaust system **110**

includes an EGR cooler (EGR-C) **118** which cools the gas exiting the exhaust manifold **106** before the gas returns to the intake manifold **104**. The exhaust system **110** may also include an EGR-C bypass valve **117** which can be opened to route a portion or all of the recirculated exhaust gas from the exhaust manifold **106** to bypass the EGR-C **118**. By increasing the amount of gas that bypasses the EGR-C **118**, the temperature of the gas returning to the intake manifold **104** is increased. It shall be appreciated that the intake system **108** and/or the exhaust system **110** may further include various components not shown, such as additional coolers, valves, bypasses, intake throttle valves, exhaust throttle valves, and/or compressor bypass valves, for example.

System **100** includes an exhaust aftertreatment (AT) system **136** which includes a diesel oxidation catalyst (DOC) **138**, a diesel particulate filter (DPF) **140**, aftertreatment (AT) heater **142**, and a selective catalytic reduction (SCR) **144**. In the example embodiment, the AT heater **142** is optionally included in the AT system **136** to increase the temperature of the exhaust gas provided to the SCR **144** within the AT system **136**. It should be noted that AT heater **142** can include one or more electric heaters distributed at various locations at, on, within, or upstream of SCR **144** or other catalyst elements of AT system **136**.

System **100** includes an electronic control system (ECS) **130**. In the illustrated embodiment, ECS **130** include an engine control unit (ECU) **132**, an aftertreatment control unit (ACU) **133**, a heater control unit (HCU) **134**, and power system control unit (PSCU) **135** which are operatively communicatively coupled with one another via one or more datalinks **131** which may comprise one or more controller area networks (CAN) and/or other types of datalinks. System **100** may include a number of other control units and controller as will occur to one of skill in the art with the benefit and insight of the present disclosure.

ECU **132** is operatively communicatively coupled with and configured and operable to control operation of and/or receive inputs from actuators, controllers, devices, sensors, and/or other components of system **100** including, for example, a number of the aforementioned features of system **100**.

HCU **134** is operatively coupled with and configured and operable to control operation of and/or receive inputs from AT heater **142**. It shall be appreciated that various communications hardware and protocols may be utilized to implement, such as one or more controller area networks (CAN) or other communications components.

PSCU **135** operatively communicatively coupled with and configured and operable to control operation of and/or receive inputs from an electrical power system of system **100** such as, for example, a motor generator system, a battery system, or other types of electrical power systems.

ECU **132**, ACU **133**, HCU **134**, PSCU **135**, and other components of ECS **130** may include one or more programmable controllers of a solid-state, integrated circuit type, and one or more non-transitory memory media configured to store instructions executable by the one or more microcontrollers. For purposes of the present application the term controller shall be understood to also encompass microcontrollers, microprocessors, application specific integrated circuits (ASIC), other types of integrated circuit processors and combinations thereof.

ECU **132**, ACU **133**, HCU **134**, PSCU **135**, and other components of ECS **130** may be implemented in any of a number of ways that combine or distribute the control function across one or more control units in various manners. The ECS **130** may execute operating logic that defines

various control, management, and/or regulation functions. This operating logic may be in the form of dedicated hardware, such as a hardwired state machine, analog calculating machine, programming instructions, and/or a different form as would occur to those skilled in the art. The ECS **130** may be provided as a single component or a collection of operatively coupled components; and may be comprised of digital circuitry, analog circuitry, or a hybrid combination of both of these types. When of a multi-component form, the ECS **130** may have one or more components remotely located relative to the others in a distributed arrangement. The ECS **130** can include multiple processing units arranged to operate independently, in a pipeline processing arrangement, in a parallel processing arrangement, or the like. It shall be further appreciated that the ECS **130** and/or any of its constituent components may include one or more signal conditioners, modulators, demodulators, Arithmetic Logic Units (ALUs), Central Processing Units (CPUs), limiters, oscillators, control clocks, amplifiers, signal conditioners, filters, format converters, communication ports, clamps, delay devices, memory devices, Analog to Digital (A/D) converters, Digital to Analog (D/A) converters, and/or different circuitry or components as would occur to those skilled in the art to perform the desired communications.

ECU **132**, ACU **133**, HCU **134**, PSCU **135**, and other components of ECS **130** may include one or more non-transitory memory devices configured to store instructions in memory which are readable and executable by a controller to control operation of engine **102** as described herein. Certain control operations described herein include operations to determine one or more parameters. ECU **132**, ACU **133**, HCU **134**, PSCU **135**, and other components of ECS **130** may be configured to determine and may perform acts of determining in a number of manners, for example, by calculating or computing a value, obtaining a value from a lookup table or using a lookup operation, receiving values from a datalink or network communication, receiving an electronic signal (e.g., a voltage, frequency, current, or pulse-width modulation (PWM) signal) indicative of the value, receiving a parameter indicative of the value, reading the value from a memory location on a computer-readable medium, receiving the value as a run-time parameter, and/or by receiving a value by which the interpreted parameter can be calculated, and/or by referencing a default value that is interpreted to be the parameter value.

With reference to FIGS. **2** and **3**, there are illustrated certain aspects of an example electronic control system (ECS) **230**. In the illustrated example, ECS **230** includes a first electronic control unit which is configured and provided in the form of heater control unit (HCU) **234**. In the illustrated example, ECS **230** also includes, a second electronic control unit which is configured and provided in the form of functional safety control unit (FSCU) **232**. In the illustrated example, ECS **230** further includes a third electronic control unit which is configured and provided in the form of power system control unit (PSCU) **219**.

ECS **230** is one example of an electronic control system including at least one electronic control unit configured to satisfy a predetermined functional safety (FuSa) requirement and at least one other electronic control configured not to satisfy the FuSa requirement. It shall be appreciated that functional safety may be formally defined as absence of a defined risk due to hazards caused by malfunctioning behavior of electrical and/or electronic systems. A number of predetermined FuSa requirements are contemplated according to the preset disclosure including, for example, the automotive safety integrity level (ASIL) requirements of the

ISO 26262 standard, namely ASIL A, ASIL B, ASIL C, and ASIL D requirements. Furthermore, an electronic control unit may be configured not to satisfy a given FuSa requirement due to its satisfying only a lower FuSa requirement, for example, a requirement of a lower ASIL, or by not satisfying any FuSa requirement, for example, being configured according to the quality management (QM) level requirements of the ISO 26262 standard.

In the illustrated example, FSCU 232 is configured to meet a predetermined FuSa requirement. In some embodiments, for example, FSCU 232 may be configured to meet FuSa requirements of ASIL C. In other embodiments, FSCU 232 may be configured to meet other FuSa requirements, for example, requirement of another ASIL level or other FuSa requirements according to other standards.

HCU 234 is configured not to meet the predetermined FuSa requirements which FSCU 232 is configured to meet. In some embodiments, for example, HCU 234 may be configured to satisfy quality management (QM) requirements, and not to meet any ASIL level. In other embodiments, HCU 234 may be configured to meet a lower FuSa requirement than FSCU 232, for example, a lower ASIL level than FSCU 232 or a lower level of other FuSa requirements.

In some embodiments, PSCU 219 may be configured to meet the predetermined FuSa requirements which FSCU 232 is configured to meet or to meet a higher FuSa requirement, such as a higher ASIL level. In some embodiments, PSCU 219 may be configured not to meet the predetermined FuSa requirements which FSCU 232 is configured to meet. In some embodiments, for example, PSCU 219 may be configured to satisfy quality management (QM) requirements, and not to meet any ASIL level. In other embodiments, PSCU 219 may be configured to meet a lower FuSa requirement than FSCU 232, for example, a lower ASIL level than FSCU 232 or a lower level of other FuSa requirements.

In the illustrated example, HCU 234 is configured and provided with two output channels. A first output channel of HCU 234 is configured to drive heater 242 using power from power supply (PS) 220 and power converter 236 which is operatively coupled with and configured to receive power from power supply 220 to selectably power load 245 of heater 242. A second output channel of HCU 234 is configured to drive heater 262 using power from power supply 220 and power converter 266 which is operatively coupled with and configured to receive power from power supply 220 to selectably power load 265 of heater 262.

PSCU 219 is configured and operable to control operation of power supply 220. power supply 220 may be configured and provided in a number of forms including, for example, electrical power systems including a battery-based power source, an alternator-based or generator-based power source, a battery and alternator or generator-based power source, or other types of electrical power source as will occur to one of skill in the art with the benefit and insight of the present disclosure. In some embodiments, electrical power source may be configured and provided as a 48V DC electrical power source.

It shall be appreciated that ECS 130 of system 100 may be configured and provided in forms according to ECS 230 or variations thereof. In some such forms, HCU 134 may correspond to HCU 234 and heater 242 may correspond to heater 142. In some such forms, FSCU 232 may correspond to ECU 132. In some such forms, FSCU 232 may correspond to ACU 133. In some such forms, FSCU 232 may

correspond to another electronic control unit of ECS 130. In some such forms, PSCU 219 may correspond to PSCU 135.

FSCU 232 is configured to send communication to HCU 234 and receive communication from HCU 234 via one or more datalinks 210 which may be configured and provided, for example, as one or more controller area networks (CAN) or one or more other types of data links. FSCU 232 is also configured to provide electrical power via line 212 and interlock enable signal 211 to HCU 234. FSCU 232 is further configured to receive FuSa feedback 218 and FuSa feedback 268 from HCU 234.

FSCU 232 supplies power from power supply 205 to HCU 234 via line 212 and high side driver (HSD) 206. In the illustrated embodiment power supply 205 is provided separately from power supply 220 and is configured to supply electrical power at a lower voltage than power supply 220. In some embodiments, for example, power supply 205 may comprise a 12V or a 24V electrical power supply. In other embodiment, power supply 205 may be configured to provide power at the same voltage as power supply 220. In some such embodiments, power supply 205 and power supply 220 may be combined or may comprise one and the same power supply. HSD 206 includes one or more switches that are controlled by microcontroller 207 to selectably turn on a supply of electrical power to HCU 234 and to turn off the supply of electrical power from power supply 205 to HCU 234.

Microcontroller 207 is configured to receive FuSa feedback 218 and FuSa feedback 268 from HCU 234 and to evaluate or process FuSa feedback 218 and FuSa feedback 268 to evaluate one or more FuSa conditions and to perform one or more FuSa operations. A number of types of FuSa feedback, FuSa evaluations, and FuSa operations are contemplated.

In some embodiments, FuSa feedback 218 may comprise one or more voltage values which may be evaluated by microcontroller 207 relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of heater 242. Similarly FuSa feedback 268 may comprise one or more voltage values which may be evaluated by microcontroller 207 relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of heater 262.

In some embodiments, FuSa feedback 218 may consist of or may consist essentially of one or more voltage values which may be evaluated by microcontroller 207 relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of heater 242. Similarly FuSa feedback 268 may consist of or may consist essentially of one or more voltage values which may be evaluated by microcontroller 207 relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of heater 262.

In some embodiments, FuSa feedback 218 may comprise one or more current values which may be evaluated by microcontroller 207 relative to one or more current thresholds to evaluate or identify an under-voltage and/or over-voltage condition of heater 242. Similarly, FuSa feedback 268 may comprise one or more current values which may be evaluated by microcontroller 207 relative to one or more current thresholds to evaluate or identify an under-voltage and/or over-voltage condition of heater 262.

In some embodiments, FuSa feedback 218 may comprise one or more temperature values which may be evaluated by microcontroller 207 relative to one or more temperature thresholds to evaluate or identify an over-temperature condition of heater 242. Similarly, FuSa feedback 268 may

comprise one or more temperature values which may be evaluated by microcontroller 207 relative to one or more temperature thresholds to evaluate or identify an over-temperature condition of heater 262.

In some embodiments, FuSa feedback 218 and FuSa feedback 268 may comprise combinations of the foregoing values or other values which may be evaluated by microcontroller 207 relative to corresponding thresholds.

Microcontroller 207 may be configured to perform a number of FuSa operations. In some embodiments, in response to an evaluation or determination of either one or both of FuSa feedback 218 indicating a fault condition of heater 242 and FuSa feedback 268 indicating a fault condition of heater 262, microcontroller 207 may set interlock enable 211 to a logical false value and output the same to interlock circuitry 233 of HCU 234. In response, interlock circuitry 233 may disable one or both of operation of HCU 234 to drive load 245 of heater 242 and operation of HCU 234 to drive load 265 of heater 262. Such disabling may occur, for example, by disabling operation of driver integrated circuit (IC) 235 and/or power converter 236.

In some instances, disabling performed in connection with interlock may be channel specific such that a determination of FuSa feedback 218 indicating a fault condition of heater 242 is effective to disable only operation of HCU 234 to drive load 245 of heater 242, and a determination of FuSa feedback 268 indicating a fault condition of heater 262 is effective to disable only operation of HCU 234 to drive load 265 of heater 262. In some instances, such disabling may be channel non-specific or channel independent such that a determination of either or both FuSa feedback 218 indicating a fault condition of heater 242 and FuSa feedback 268 indicating a fault condition of heater 262 is effective to disable operation of HCU 234 to drive load 245 of heater 242 and to disable operation of HCU 234 to drive load 265 of heater 262.

In some embodiments, in response to an evaluation or determination of either one or both of FuSa feedback 218 indicating a fault condition of heater 242 and FuSa feedback 268 indicating a fault condition of heater 262, microcontroller 207 may control HSD 206 to turn off or disable a supply of power to HCU 234 via line 212 which, in turn, is effective to disable operation of microcontroller 231, driver IC 235, power converter 236, driver IC 265, and power converter 266.

In some embodiments, in response to an evaluation or determination of either one or both of FuSa feedback 218 indicating a fault condition of heater 242 and FuSa feedback 268 indicating a fault condition of heater 262, microcontroller 207 may send one or more commands to HCU 234 via datalink 210 which may be executed by microcontroller 231 to end or suspend operation of one or both of driver IC 235 and power converter 236, and driver IC 265 and power converter 266.

In some embodiments, microcontroller 207 may be configured to implement and execute combinations of any pair of the foregoing FuSa operations or a combination of all three of the foregoing operations. Microcontroller 207 may also be configured to implement and execute other functional safety logic and operations, for example, as further described elsewhere herein. It shall be further appreciated that microcontroller 207 and/or microcontroller 231 may be configured to perform a number of diagnostics in response to the FuSa feedbacks disclosed herein. Example of such diagnostics include first order diagnostics such as over-voltage fault, under-voltage fault, over-current fault, under-current fault, and over temperature fault conditions. Further

examples of such diagnostics include higher order diagnostics such as diagnostics or prognostics indicative of current or future component malfunction or failure which may be based upon trends and other analytics performed on multiple instance of first order diagnostics and various other diagnostics.

FSCU 232 supplies electrical power via line 212 to microcontroller 231. In some embodiments, FSCU 232 may additionally supply electrical power via line 212 to driver IC 235, driver IC 265, and interlock circuitry 233, as well as to other control circuitry of HCU 234. FSCU 232 may also selectably supply enable signals and control signals to microcontroller 231 via one or more datalinks 210 to selectably enable and command operation of microcontroller 231 to control driver IC 235 and power converter 236 to drive a load 245 of heater 242 and to selectably enable and command operation of microcontroller 231 to control driver IC 265 and power converter 266 to drive a load 265 of heater 262. Additional control signals may be similarly provided to cause microcontroller 231 to enter a sleep mode or to wake from a sleep mode or otherwise adjust, control, or program, microcontroller 231.

One or more sensors 246 are configured to sense one or more operational characteristics of or associated with load 245 of heater 242. The one or more sensors 246 may comprise, for example, one or more voltage sensors configured to sense a voltage of or associated with load 245, one or more current sensors configured to sense a current of or associated with load 245, and/or one or more temperature sensors configured to sense a temperature of or associated with load 245.

Output of the one or more sensors 246 may be provided as or utilized in determining FuSa feedback 218. In the illustrated example, FuSa feedback 218 is also provided to microcontroller 231 which may perform similar evaluations of FuSa feedback 218 as microcontroller 207 but without meeting the FuSa requirements of FSCU 232. FuSa feedback 218 is preferably provided to FSCU 232 via a communication link with the ability to operate independently of other control circuitry of HCU 234, for example, via one or more dedicated communication links.

One or more sensors 266 are configured to sense one or more operational characteristics of or associated with load 265 of heater 262. The one or more sensors 266 may comprise, for example, one or more voltage sensors configured to sense a voltage of or associated with load 265, one or more current sensors configured to sense a current of or associated with load 265, and/or one or more temperature sensors configured to sense a temperature of or associated with load 265.

Output of the one or more sensors 266 may be provided as or utilized in determining FuSa feedback 268. In the illustrated example, FuSa feedback 268 is also provided to microcontroller 231 which may perform similar evaluations of FuSa feedback 268 as microcontroller 207 but without meeting the FuSa requirements of FSCU 232. FuSa feedback 268 is preferably provided to FSCU 232 via a communication link with the ability to operate independently of other control circuitry of HCU 234, for example, via one or more dedicated communication links which may be the same as or separate and distinct from the one or more dedicated communication links over which FuSa feedback 218 is transmitted.

In the illustrated embodiment, power converter 236 is configured and provided as a DC-DC power converter which is operatively coupled with and configured to receive DC power from power supply 220 which may provide such

electrical power from one or more electrical storage and/or generation systems. In some forms, power converter **236** may be configured and provided in the form of a buck converter such as an interleaved buck converter. In other embodiments, power converter **236** may be configured and provided as another type of DC-DC converter. In other embodiments, power converter **236** may be configured and provided as AC-DC power converter which is operatively coupled with and configured to receive AC power from power supply **220**.

Power converter **236** is further operatively coupled with and configured to drive heater **242** using power from power supply **220**. Driver integrated circuit (IC) **234** is operatively coupled with and configured to receive control commands from microcontroller **231** and, in response to such control commands, to provide output to drive power converter **236**. Driver IC **235** is also operatively coupled with and configured to receive an enable command or signal from interlock circuitry **233**.

In the illustrated embodiment, power converter **266** is configured and provided as a DC-DC power converter which is operatively coupled with and configured to receive DC power from power supply **220** which may provide such electrical power from one or more electrical storage and/or generation systems. In some forms, power converter **266** may be configured and provided in the form of a buck converter such as an interleaved buck converter. In other embodiments, power converter **266** may be configured and provided as another type of DC-DC converter. In other embodiments, power converter **266** may be configured and provided as AC-DC power converter which is operatively coupled with and configured to receive AC power from power supply **220**.

Power converter **266** is further operatively coupled with and configured to drive heater **242** using power from power supply **220**. Driver integrated circuit (IC) **265** is operatively coupled with and configured to receive control commands from microcontroller **231** and, in response to such control commands, to provide output to drive power converter **266**. Driver IC is also operatively coupled with and configured to receive an enable command or signal from interlock circuitry **233**.

Interlock circuitry **233** is operatively coupled with and configured to receive interlock enable signal **211** from FSCU **232**. In the illustrated embodiment, interlock circuitry **233** is also operatively coupled with another interlock enable signal from microcontroller **231**, and an enable signal from a watchdog timer which may be implemented in or in connection with microcontroller **231** or other control circuitry HCU **234** or FSCU **232**. Interlock circuitry **233** may be configured to disable operation of HCU when any one or more of the inputs which it receives has a logical false value.

FSCU **232** is configured to send communication to PSCU **219** and receive communication from PSCU **219** via one or more datalinks **210**. FSCU **232** is also configured to provide enable signal **281** to PSCU **219**. Enable signal **281** may be sent and utilized to switch off PSCU **219** and thereby indirectly disable operation of HCU **234** under certain conditions, for example, if an error, fault, or malfunction prevents FSCU **232** from successfully disabling or shutting off HCU **234** in the event of an error, fault, or malfunction. In some embodiments, FSCU **232** may additionally be configured to send electrical power to control circuitry of PSCU **219** and/or to receive additional FuSA feedback from PSCU **219** to provide a substantially similar functional safety relationship and functionality of FSCU **232** and PSCU **219** as that of FSCU **232** and HCU **234**.

The architectures and topologies described in connection with FIGS. **1-3** may be utilized and provide in a number of forms. Some such forms may comprise a first power converter channel such as the channel of power converter **236** configured to drive a first heater such as heater **242**, and a second power converter channel such as the channel of power converter **266** configured to drive a second heater such as heater **262**. Some such forms may comprise different arrangement of multichannel power converters and heater loads including the following examples.

With reference to FIG. **4**, there are illustrated certain aspects of another example electronic control system (ECS) **430** providing another example arrangement of multichannel power converters and heater loads. A number of the illustrated features of ECS **430** generally correspond to those of ECS **230** with the reference numerals of ECS **430** being incremented by 200. It shall likewise be appreciated that ECS **430** includes the other features described in connection with of ECS **230** which are not illustrated in FIG. **4**.

In ECS **430**, HCU **434** includes a first output channel via which power converter **436** selectively outputs power to drive heater **442** and a second output channel via which power converter **466** selectively outputs power to drive heater **442**. This arrangement allows the heater to be driven at twice the rated power that would be provided by a single channel output. For example, two 5 kW channels may drive a 10 kW heater load, or two 10 kW channels may drive a 20 kW heater.

With reference to FIG. **5**, there are illustrated certain aspects of another example electronic control system (ECS) **530** providing another example arrangement of multichannel power converters and heater loads. A number of the illustrated features of ECS **530** generally correspond to those of ECS **230** with the reference numerals of ECS **530** being incremented by 300. It shall likewise be appreciated that ECS **530** includes the other features described in connection with of ECS **230** which are not illustrated in FIG. **5**.

In ECS **530**, HCU **534** includes a first output channel via which power converter **536** selectively outputs power to drive heater **542** and a second output channel via which power converter **566** selectively outputs power to drive heater **542**. ECS **530** further includes a switch **503** which is controllable by HCU **534** and/or FSCU **532** to selectively couple and decouple the second output channel from heater **542**. This arrangement allows the heater to be selectively driven at a single channel rated power and a double the single channel rated power. For example, two 5 kW channels may be selectively operated to drive heater load at 5 kW or at 10 kW, or two 10 kW channels may be selectively operated to drive a heater load at 10 kW or at 20 kW.

With reference to FIG. **6**, there are illustrated certain aspects of another example electronic control system (ECS) **630** providing another example arrangement of multichannel power converters and heater loads. A number of the illustrated features of ECS **630** generally correspond to those of ECS **230** with the reference numerals of ECS **630** being incremented by 400. Furthermore, additional instance of such features are indicated with reference numerals incremented by 400 followed by an apostrophe or prime symbol. It shall likewise be appreciated that ECS **630** includes the other features described in connection with of ECS **230** which are not illustrated in FIG. **6**.

In ECS **630**, HCU **634** includes a first output channel via which power converter **636** selectively outputs power to drive heater **642** and a second output channel via which power converter **666** selectively outputs power to drive heater **642**. This arrangement allows the heater to be driven

at twice the rated power that would be provided by a single channel output. For example, two 5 kW channels may drive a 10 kW heater load, or two 10 kW channels may drive a 20 kW heater. It is further contemplated that a switch similar to switch **503** of ECS **530** may be provided to provide the functionality described in connection therewith.

In ECS **630**, HCU **634'** includes a first output channel via which power converter **636'** selectably outputs power to drive heater **642'** and a second output channel via which power converter **666'** selectably outputs power to drive heater **642'**. This arrangement allows the heater to be driven at twice the rated power that would be provided by a single channel output. For example, two 5 kW channels may drive a 10 kW heater load, or two 10 kW channels may drive a 20 kW heater. It is further contemplated that a switch similar to switch **503** of ECS **530** may be provided to provide the functionality described in connection therewith.

With reference to FIG. 7, there is illustrated a flowchart depicting certain aspects of an example control process **700** (also referred to herein as process **700**). Process **700** is described in connection with a first ECU and a second ECU. The first ECU may correspond to HCU **234**, any of the other HCU described herein, or to another electronic control unit configured not to satisfy a predetermined functional safety (FuSa) requirement. The second ECU may correspond to FSCU **232**, any of the other FSCU described herein, or to another electronic control unit configured to satisfy the predetermined FuSa requirement.

Process **700** begins at start operation **702** and proceeds to operation **704** at which the second ECU enables operation of the first ECU, for example, by setting a logical value of an interlock enable signal to true and/or by outputting a wake signal to the first ECU. From operation **704**, process **700** proceeds to operation **706** at which the second ECU sends a power up command to the first ECU. From operation **706**, process **700** proceeds to operation **708** at which the first ECU turns on one or more out channels to drive a load (e.g., a heater coil) of one or more heaters.

From operation **708**, process **700** proceeds to operation **710** at which the second ECU reads one or more FuSa feedback parameters providing information indicative of a state of one or more corresponding output channels of the first ECU. In some embodiments, the one or more FuSa feedback parameters may comprise one or more voltage values which may be evaluated relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of the heater. In some embodiments, the one or more FuSa feedback parameters may consist of or consist essentially of one or more voltage values which may be evaluated relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of the heater. In some embodiments, the one or more FuSa feedback parameters may comprise one or more current values which may be evaluated relative to one or more current thresholds to evaluate or identify an under-current and/or over-current condition of the heater. In some embodiments, the one or more FuSa feedback parameters may comprise one or more temperature values which may be evaluated relative to one or more temperature thresholds to evaluate or identify an over-temperature condition of the heater. In some embodiments, the one or more FuSa feedback parameters may comprise combinations of the foregoing values or other values which may be relative to corresponding thresholds.

From operation **710**, process **700** proceeds to operation **712** at which the second ECU evaluates the one or more FuSa feedback for one or more fault conditions. In some

embodiments, the evaluating the one or more FuSa feedback parameters may comprise evaluating one or more voltage values relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition. In some embodiments, the evaluating the one or more FuSa feedback parameters may consist of or consist essentially of evaluating one or more voltage values relative to one or more voltage thresholds to evaluate or identify an under-voltage and/or over-voltage condition of the heater. In some embodiments, the evaluating the one or more FuSa feedback parameters may comprise evaluating one or more current values relative to one or more current thresholds to evaluate or identify an under-current and/or over-current condition of the heater. In some embodiments, the evaluating the one or more FuSa feedback parameters may comprise evaluating one or more temperature values relative to one or more temperature thresholds to evaluate or identify an over-temperature condition of the heater. In some embodiments, the evaluating the one or more FuSa feedback parameters may comprise combinations of the foregoing evaluations or other evaluations relative to corresponding thresholds.

If conditional **712** evaluates negative, process **700** proceeds to operation **710**. If conditional **712** evaluates affirmative, process **700** proceeds to operation **714** at which the second ECU sets a fault value equal to true and sets disables operation of the first ECU, for example, by setting a logical value of an interlock enable signal to false, by turning off power to the first ECU, by commanding the first ECU not to operate, or by performing a combination of two or more the foregoing operations or other operations.

From operation **714**, process **700** proceeds to conditional **716** which evaluates whether a fault condition is true. If conditional **716** evaluates negative, process **700** proceeds to operation **714**. If conditional **716** evaluates affirmative process **700** proceeds to conditional **712**.

As shown by this detailed description, the present disclosure contemplates multiple and various embodiments, including, without limitation, the following example embodiments.

A first example embodiment is a prime mover system comprising: an engine; an aftertreatment system configured to treat exhaust of the engine; an electrical power source; a heater configured to selectably heat the aftertreatment system; and an electronic control system comprising a first electronic control unit configured to selectably drive the heater using power from the electrical power source, and a second electronic control unit configured to selectably enable and disable operation of the first electronic control unit to drive the heater in response to a feedback received from the first electronic control unit, the second electronic control unit being configured to meet predetermined functional safety requirements, the first electronic control unit being configured not to meet the predetermined functional safety requirements.

A second example embodiment includes the features of the first example embodiment, wherein the first electronic control unit comprises a power converter configured to convert power from the electrical power source to power the heater, and interlock circuitry configured to selectably enable and disable the power converter in response to a signal received from the second electronic control unit.

A third example embodiment includes the features of the first example embodiment, wherein the second electronic control unit is configured to supply electrical power from a second electrical power source to control circuitry of the first electronic control unit, the second electrical power source being independent of the electrical power source.

A fourth example embodiment includes the features of the third example embodiment, wherein the second electronic control unit is configured to selectably turn off the supply of electrical power to control circuitry of the first electronic control unit in response to the feedback.

A fifth example embodiment includes the features of the first example embodiment, wherein the feedback comprises a feedback indicative of a voltage of the heater.

A sixth example embodiment includes the features of the fifth example embodiment, wherein the second electronic control unit is configured to evaluate the feedback and to selectably disable operation of the first electronic control unit to drive the heater in response to an evaluation of the feedback received indicating one of an over-voltage condition and an under-voltage condition of the heater.

A seventh example embodiment includes the features of the first example embodiment, wherein the first electronic control unit includes a first power output channel and a second power output channel configured to selectably drive the heater.

An eighth example embodiment includes the features of the first example embodiment, wherein the electronic control system comprises a third electronic control unit configured to selectably drive the heater using power from the electrical power source, the second electronic control unit being configured to selectably enable and disable operation of the third electronic control unit to drive the second heater in response to a second feedback received from the third electronic control unit, the third electronic control configured not to meet the predetermined functional safety requirements.

A ninth example embodiment includes the features of the first example embodiment, wherein the electronic control system comprises a third electronic control unit configured to selectably drive a second heater using power from the electrical power source, the second electronic control unit being configured to selectably enable and disable operation of the third electronic control unit to drive the second heater in response to a second feedback received from the third electronic control unit, the third electronic control configured not to meet the predetermined functional safety requirements.

A tenth example embodiment is a process for controlling a prime mover system including an engine, an aftertreatment system configured to treat exhaust of the engine, an electrical power source, and a heater configured to selectably heat the aftertreatment system, and an electronic control system, the process comprising: operating a first electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source, providing a feedback from the first electronic control unit to a second electronic control unit of the electronic control system, and operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit to drive the heater in response to the feedback, wherein the operating the second electronic control unit satisfies predetermined functional safety requirements, and the operating the first electronic control unit does not satisfy the predetermined functional safety requirements.

An eleventh example embodiment includes the features of the tenth example embodiment, wherein the operating a first electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source comprises operating a power converter of the first electronic control unit to convert power from the electrical power source to power the heater, and operating interlock circuitry to selectably enable operation of the

power converter in response to a signal received from the second electronic control unit.

A twelfth example embodiment includes the features of the tenth example embodiment, comprising operating the second electronic control unit to supply electrical power from a second electrical power source to control circuitry of the first electronic control unit, the second electrical power source being independent of the first electrical power source.

A thirteenth example embodiment includes the features of the twelfth example embodiment, comprising operating the second electronic control unit to selectably turn off the supply of electrical power to control circuitry of the first electronic control unit in response to the feedback.

A fourteenth example embodiment includes the features of the tenth example embodiment, wherein the feedback comprises a feedback indicative of a voltage of the heater.

A fifteenth example embodiment includes the features of the fourteenth example embodiment, comprising operating the second electronic control unit to evaluate the feedback and to selectably disable operation of the first electronic control unit to drive the heater in response to an evaluation of the feedback received indicating one of an over-voltage condition and an under-voltage condition of the heater.

A sixteenth example embodiment includes the features of the tenth example embodiment, wherein the operating a first electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source comprises selectably driving the heater with a first a first power output channel and a second power output channel of the first electronic control unit.

A seventeenth example embodiment includes the features of the tenth example embodiment, comprising: operating a third electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source; providing a second feedback from the third electronic control unit to the second electronic control unit; and operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit to drive the heater in response to the feedback; wherein the operating the third electronic control unit does not satisfy the predetermined functional safety requirements.

An eighteenth example embodiment includes the features of the tenth example embodiment, comprising: operating a third electronic control unit of the electronic control system to selectably drive a second heater using power from the electrical power source; providing a second feedback from the third electronic control unit to the second electronic control unit; and operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit to drive the second heater in response to the feedback; wherein the operating the third electronic control unit does not satisfy the predetermined functional safety requirements.

A nineteenth example embodiment is an apparatus for controlling a prime mover system including an engine, an aftertreatment system configured to treat exhaust of the engine, an electrical power source, and a heater configured to selectably heat the aftertreatment system, the apparatus comprising: an electronic control system including a first electronic control unit configured to selectably drive the heater using power from the electrical power source, and a second electronic control unit configured to selectably enable and disable operation of the first electronic control unit to drive the heater in response to a feedback received from the first electronic control unit, wherein the second electronic control unit is configured to meet predetermined

15

functional safety requirements, and the first electronic control configured not to meet the predetermined functional safety requirements.

A twentieth example embodiment includes the features of the nineteenth example embodiment, wherein the first electronic control unit comprises a power converter configured to convert power from the electrical power source to power the heater, and interlock circuitry configured to selectably enable and disable the power converter in response to a signal received from the second electronic control unit.

A twenty-first example embodiment includes the features of the nineteenth example embodiment, wherein the second electronic control unit is configured to supply electrical power from a second electrical power source to control circuitry of the first electronic control unit, the second electrical power source being independent of the first electrical power source.

A twenty-second example embodiment includes the features of the twenty-first example embodiment, wherein the second electronic control unit is configured to selectably turn off the supply of electrical power to control circuitry of the first electronic control unit in response to the feedback.

It shall be appreciated that terms such as “a non-transitory memory,” “a non-transitory memory medium,” and “a non-transitory memory device” refer to a number of types of devices and storage mediums which may be configured to store information, such as data or instructions, readable or executable by a processor or other components of a computer system and that such terms include and encompass a single or unitary device or medium storing such information, multiple devices or media across or among which respective portions of such information are stored, and multiple devices or media across or among which multiple copies of such information are stored.

It shall be appreciated that terms such as “determine,” “determined,” “determining” and the like when utilized in connection with a control method or process, an electronic control system or controller, electronic controls, or components or operations of the foregoing refer inclusively to a number of acts, configurations, devices, operations, and techniques including, without limitation, calculation or computation of a parameter or value, obtaining a parameter or value from a lookup table or using a lookup operation, receiving parameters or values from a datalink or network communication, receiving an electronic signal (e.g., a voltage, frequency, current, or pulse-width modulation (PWM) signal) indicative of the parameter or value, receiving output of a sensor indicative of the parameter or value, receiving other outputs or inputs indicative of the parameter or value, reading the parameter or value from a memory location on a computer-readable medium, receiving the parameter or value as a run-time parameter, and/or by receiving a parameter or value by which the interpreted parameter can be calculated, and/or by referencing a default value that is interpreted to be the parameter value.

While example embodiments of the disclosure have been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only certain example embodiments have been shown and described and that all changes and modifications that come within the spirit of the claimed inventions are desired to be protected. It should be understood that while the use of words such as preferable, preferably, preferred or more preferred utilized in the description above indicates that the feature so described may be more desirable, it nonetheless may not be necessary and embodiments lacking

16

the same may be contemplated as within the scope of the invention, the scope being defined by the claims that follow. In reading the claims, it is intended that when words such as “a,” “an,” “at least one,” or “at least one portion” are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language “at least a portion” and/or “a portion” is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

What is claimed is:

1. A prime mover system comprising:
 - an engine;
 - an aftertreatment system configured to treat exhaust of the engine;
 - an electrical power source;
 - a heater configured to selectably heat the aftertreatment system; and
 - an electronic control system comprising a first electronic control unit configured to selectably drive the heater using power from the electrical power source, and a second electronic control unit configured to selectably enable and disable operation of the first electronic control unit to drive the heater in response to a feedback received from the first electronic control unit, the second electronic control unit being configured to meet predetermined functional safety requirements, the first electronic control unit being configured not to meet the predetermined functional safety requirements, wherein the second electronic control unit is configured to selectably enable and disable operation of the first electronic control unit using a first signal sent via a first datalink from a microcontroller of the second electronic control unit to a microcontroller of the first electronic control unit, and a second signal sent via a second datalink from the microcontroller of the second electronic control to interlock circuitry configured to disable a driver of the first electronic control unit.
2. The prime mover system of claim 1, wherein the first electronic control unit comprises a power converter configured to convert power from the electrical power source to power the heater.
3. The prime mover system of claim 1, wherein the second electronic control unit is configured to supply electrical power from a second electrical power source to control circuitry of the first electronic control unit, the second electrical power source being independent of the electrical power source.
4. The prime mover system of claim 3, wherein the second electronic control unit is configured to selectably turn off the supply of electrical power to control circuitry of the first electronic control unit in response to the feedback.
5. The prime mover system of claim 1, wherein the feedback comprises a feedback indicative of a voltage of the heater.
6. The prime mover system of claim 5, wherein the second electronic control unit is configured to evaluate the feedback and to selectably disable operation of the first electronic control unit to drive the heater in response to an evaluation of the feedback received indicating one of an over-voltage condition and an under-voltage condition of the heater.
7. The prime mover system of claim 1, wherein the first electronic control unit includes a first power output channel and a second power output channel configured to selectably drive the heater.
8. The prime mover system of claim 1, wherein the electronic control system comprises a third electronic control unit configured to selectably drive the heater using

17

power from the electrical power source, the second electronic control unit being configured to selectably enable and disable operation of the third electronic control unit to drive the second heater in response to a second feedback received from the third electronic control unit, the third electronic control configured not to meet the predetermined functional safety requirements.

9. The prime mover system of claim 1, wherein the electronic control system comprises a third electronic control unit configured to selectably drive a second heater using power from the electrical power source, the second electronic control unit being configured to selectably enable and disable operation of the third electronic control unit to drive the second heater in response to a second feedback received from the third electronic control unit, the third electronic control configured not to meet the predetermined functional safety requirements.

10. A process for controlling a prime mover system including an engine, an aftertreatment system configured to treat exhaust of the engine, an electrical power source, and a heater configured to selectably heat the aftertreatment system, and an electronic control system, the process comprising:

operating a first electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source,

providing a feedback from the first electronic control unit to a second electronic control unit of the electronic control system, and

operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit to drive the heater in response to the feedback,

wherein the operating the second electronic control unit satisfies predetermined functional safety requirements, and the operating the first electronic control unit does not satisfy the predetermined functional safety requirements

wherein operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit comprises either or both of sending a first signal from a microcontroller of the second electronic control unit to a microcontroller of the first electronic control unit, and sending a second signal sent from the microcontroller of the second electronic control to interlock circuitry configured to disable a driver of the first electronic control unit.

11. The process of claim 10, wherein the operating a first electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source comprises operating a power converter of the first electronic control unit to convert power from the electrical power source to power the heater.

12. The process of claim 10, comprising operating the second electronic control unit to supply electrical power from a second electrical power source to control circuitry of the first electronic control unit, the second electrical power source being independent of the first electrical power source.

13. The process of claim 12, comprising operating the second electronic control unit to selectably turn off the supply of electrical power to control circuitry of the first electronic control unit in response to the feedback.

14. The process of claim 10, wherein the feedback comprises a feedback indicative of a voltage of the heater.

15. The process of claim 14, comprising operating the second electronic control unit to evaluate the feedback and to selectably disable operation of the first electronic control

18

unit to drive the heater in response to an evaluation of the feedback received indicating one of an over-voltage condition and an under-voltage condition of the heater.

16. The process of claim 10, wherein the operating a first electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source comprises selectably driving the heater with a first a first power output channel and a second power output channel of the first electronic control unit.

17. The process of claim 10, comprising:
operating a third electronic control unit of the electronic control system to selectably drive the heater using power from the electrical power source;

providing a second feedback from the third electronic control unit to the second electronic control unit; and operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit to drive the heater in response to the feedback;

wherein the operating the operating the third electronic control unit does not satisfy the predetermined functional safety requirements.

18. The process of claim 10, comprising:
operating a third electronic control unit of the electronic control system to selectably drive a second heater using power from the electrical power source;

providing a second feedback from the third electronic control unit to the second electronic control unit; and operating the second electronic control unit to selectably enable and disable operation of the first electronic control unit to drive the second heater in response to the feedback;

wherein the operating the operating the third electronic control unit does not satisfy the predetermined functional safety requirements.

19. An apparatus for controlling a prime mover system including an engine, an aftertreatment system configured to treat exhaust of the engine, an electrical power source, and a heater configured to selectably heat the aftertreatment system, the apparatus comprising:

an electronic control system including
a first electronic control unit configured to selectably drive the heater using power from the electrical power source, and

a second electronic control unit configured to selectably enable and disable operation of the first electronic control unit to drive the heater in response to a feedback received from the first electronic control unit,

wherein the second electronic control unit is configured to meet predetermined functional safety requirements, and the first electronic control configured not to meet the predetermined functional safety requirements,

wherein the second electronic control unit is configured to selectably enable and disable operation of the first electronic control unit using a first datalink operatively coupling a microcontroller of the second electronic control unit to a microcontroller of the first electronic control unit, and a second datalink operatively coupling from the microcontroller of the second electronic control to interlock circuitry configured to disable a driver of the first electronic control unit.

20. The apparatus of claim 19, wherein the first electronic control unit comprises a power converter configured to convert power from the electrical power source to power the heater.

21. The apparatus of claim 19, wherein the second electronic control unit is configured to supply electrical power

from a second electrical power source to control circuitry of the first electronic control unit, the second electrical power source being independent of the first electrical power source.

22. The apparatus of claim 21, wherein the second electronic control unit is configured to selectably turn off the supply of electrical power to control circuitry of the first electronic control unit in response to the feedback.

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